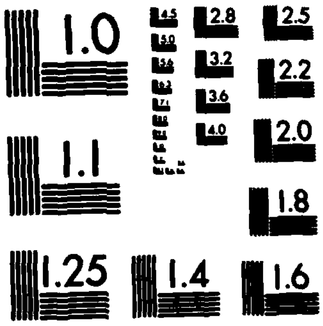
AD-A146 185 HOLOGRAPHIC DISPLACEMENT ANALYSIS WITH FIBER OPTICS(U) 1/1
WISCONSIN UNIV-MILWAUKEE J A GILBERT AUG 84
ARO-17357.19-EG DAAG29-80-K-0028

UNCLASSIFIED F/G 20/6 NL

END
FILMED
DTIC



MICROCOPY RESOLUTION TEST CHART

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: ARO 17357.19-EG	2. GOVT ACCESSION NO.: N/A
3. RECIPIENT'S CATALOG NUMBER: N/A	
4. TITLE (and Subtitle): Holographic Displacement Analysis with Fiber Optics	5. TYPE OF REPORT & PERIOD COVERED: Final Report 9 Jul 1980 - 8 Jul 1984
	6. PERFORMING ORG. REPORT NUMBER: N/A
7. AUTHOR(s): John A. Gilbert	8. CONTRACT OR GRANT NUMBER(s): DAAG29-80-K-0028
9. PERFORMING ORGANIZATION NAME AND ADDRESS: University of Wisconsin - Milwaukee	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: N/A
11. CONTROLLING OFFICE NAME AND ADDRESS: U. S. Army Research Office, P. O. Box 12211, Research Triangle Park NC 27709	12. REPORT DATE: Aug 84
	13. NUMBER OF PAGES: 20
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

THE VIEW, OPINIONS, AND/OR FINDINGS CONTAINED IN THIS REPORT ARE THOSE OF THE AUTHOR(S) AND SHOULD NOT BE CONSTRUED AS AN OFFICIAL DEPARTMENT OF THE ARMY POSITION, POLICY, OR DECISION, UNLESS SO DESIGNATED BY OTHER DOCUMENTATION.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Holography
Interferometry
Deformation
Optical Fibers

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The aim of the research reported here was to incorporate optical fibers into systems designed to measure deformation in production-related or in-situ applications where conventional techniques would be difficult or impossible to apply.

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

84 09 25 145

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ARO 17357.19-EG

HOLOGRAPHIC DISPLACEMENT ANALYSIS WITH FIBER OPTICS

FINAL REPORT

by

John A. Gilbert, Ph.D.
Associate Professor of Engineering Mechanics

August 1, 1984

ARMY RESEARCH OFFICE

Contract No. DAAG 29-80-K-0028

The Board of Regents
University of Wisconsin System
University of Wisconsin-Milwaukee
Milwaukee, Wisconsin 53201

APPROVED FOR PUBLIC RELEASE;

DISTRIBUTION UNLIMITED

A-1

FORWARD

The aim of the research conducted under ARO Contract No. DAAG 29-80-K-0028 was to incorporate optical fibers into systems designed to measure deformation in production-related or in-situ applications where conventional techniques would be difficult or impossible to apply. The original two-year contract (awarded for the period July 9, 1980 through July 8, 1982) called for three phases of research consisting of 14 separate tasks. Phase IV (consisting of two separate tasks) was added on July 9, 1982 when a one-year extension of the contract was granted "to explore new research avenues uncovered during the original contract." Four additional tasks were proposed and subsequently funded over an additional one-year period (July 9, 1983 through July 8, 1984). Further details can be found in the eight semi-annual progress reports submitted to ARO.

To date, we have addressed all, and met mostly all, of the research objectives contained in our original two-year proposal and the two one-year extensions. We have become internationally known (primarily through publications and presentations) for incorporating fiber optics into holographic interferometric and speckle photographic systems and are now recognized (based on invited papers, requests for publications and further information on our research) as one of the pioneers in applying fiber-based, photoelectronic-numerical data processing techniques in optical metrology. University/industry interaction has been significant (with Bell Laboratories, American Cystoscope, Allen Bradley, United Technologies, etc.) and we have successfully piloted

additional research directions under the current contract which have resulted in funded proposals (National Science Foundation Grant No. MEA-8305597, DoD Grant No. DAAG 29-84-G-0045). Several students have benefited from the funds made available through ARO. Seven of these have graduated and secured employment in related research areas (at Bell Laboratories, in General Electric Medical Systems Division, at General Dynamics, in Biotronics, Inc., at Yamaha, in Beloit Corporation and at Grumman Aerospace).

In short, a very solid research program has been developed in the areas of engineering mechanics and applied optics at the University of Wisconsin-Milwaukee as a direct result of ARO funding. Special thanks are extended to Dr. E. Saibel and Dr. R. Singleton of the Army Research Office for their invaluable guidance over the four-year contract period.

John A. Gilbert, Ph.D.
Principal Investigator

TABLE OF CONTENTS

STATEMENT OF THE PROBLEM STUDIED

In recent years there has been an explosion in fiber optic technology due to a rapidly growing interest in the application of optical fiber light guides to communications systems. Optical fiber research and development has now reached the point where low-loss/low-cost fiber optics suitable for a wide range of practical noncommunications applications have become readily available. At the same time, progress in the development of high quality flexible fiber optic imaging instruments, such as medical endoscopes and industrial boroscopes which use coherent bundles of many thousand of fibers, has provided additional tools with which to access remote or otherwise inaccessible subjects for viewing with exceptional accuracy and resolution. Concurrently, the development of the laser as an economical and reliable source of coherent illumination has given birth to the entire field of coherent light metrology, including holographic interferometry, laser speckle interferometry, laser speckle photography and laser doppler velocimetry. Research conducted under ARO Contract No. DAAG 29-80-K-0028 discusses the synthesis of fiber optics and two of these coherent light techniques most readily applied to studies of material deformation and structural mechanics; holographic interferometry and laser speckle photography.

Over the last decade, the work of various investigations has demonstrated the practical uses of fiber optic elements for holography and holographic interferometry,[1-19] and in more recent years, for white light speckle photography[20,21] and coherent light objective speckle photography.[22-25] Experience has

established that individual single mode optical fibers provide convenient, highly stable illuminators for holographic interferometry[9] and laser speckle photography,[22] while lensed coherent fiber optic bundles may be used to transmit holographic[3,6,9] or speckle "images"[20-22] for recording and analysis at locations remote from the actual test object. Moreover, unlensed fiber optic bundles may be used as flexible illuminators for pulsed laser holography.[12] Individual optical fibers and coherent fiber optic bundles may be used in both local and remote holographic systems, including double exposure,[6-9] time average[16] and real-time[19] holographic interferometry. Procedures for recording both image plane ("white light") and Fraunhofer holograms through fiber optics have now been developed, as well as a method for greatly suppressing the inherent instability of commercially available multimode fiber optic image bundles through the use of an "ultra low spatial frequency" (ULF) holographic technique.[13,14]

Single fiber coherent illuminators can be used to generate speckle fields whose movements are sampled either directly or by a fiber optic image bundle suitably oriented for remote access. At the present time the resolution limits of fiber optic image bundles strongly favor objective speckle systems,[22] which are fundamentally disposed towards data acquisition on a point wise rather than full field basis. However, displacement fields can be evaluated through the use of imaged "white light" or artificial speckle,[21] albeit at lower sensitivities than those possible with coherent light speckle.

Many of these findings were uncovered under ARO Contract No.

DAAG 29-80-K-0028. A summary of the the most important results of that work begins on page 11. Further details can be found in Reference 26.

REFERENCES

1. Nishida, N., Sakaguchi, M., Saito, F., Holographic coding plate: a new application of holographic memory, Appl. Opt., 12, 7 (1973).

2. Rosen, A. N., Holographic fundoscopy with fiber optic illumination, Opt. and Laser Tech., 7, 3 (1975).

3. Hadbawnik, D., Holographische endosckopie, Optik, 45, 1 (1976), p. 21-38.

4. Suhara, T., Nishihara, H., Koyama, J., Far radiation field emitted from an optical fiber and its application to holography, Trans. of the IECE of Japan. Sec E (Engl), 60, 10 (1977), p. 533-540.

5. Leite, A. M. P. P., Optical fiber illuminators for holography, Opt. Commun., 28, 3 (1979), p. 303-306.

6. Yonemura, M., Nishisaka, T., Machida, H., Endoscopic hologram interferometry using fiber optics, Appl. Opt., 28, 9 (1981), p. 1664-1667.

7. Gilbert, J.A., Herrick, J.W., Holographic displacement analysis with multimode fiber optics, Experimental Mechanics, 21, 8 (1981), p. 315-320.

8. Gilbert, J.A., Schultz, M.E., Boehnlein, A.J., Remote displacement analysis using multimode fiber optic bundles, Experimental Mechanics, 22, 10 (1982), p. 398-400.

9. Gilbert, J.A., Dudderar, T.D., Schultz, M.E., Boehnlein, A.J., The monomode fiber - a new tool for holographic interferometry, Experimental Mechanics, 23, 2 (1983), p. 190-195.

10. Rowley, D., The use of a fiber-optic reference beam in a focused image holographic interferometer, Optics and Laser Tech., 15, 4 (1983), p. 194-198.

11. Gilbert, J.A., Dudderar, T.D., Nose, A., Remote displacement analysis through different media using fiber optics, Proc. of the 1983 Spring Conf. on Exp. Mech., SESA, Cleveland, Ohio (1983), p. 424-430.

12. Dudderar, T.D., Gilbert, J.A., Fiber optic pulsed laser holography, Applied Physics Letters, 43, 8 (1983), p. 730-732.

13. Dudderar, T.D., Gilbert, J.A., Boehnlein, A.J, Achieving stability in remote holography using flexible multimode image bundles, Applied Optics, 22, 7 (1983), p. 1000-

1005.

14. Gilbert, J.A., Dudderar, T.D., Boehnlein, A.J., Ultra low frequency holographic interferometry using fiber optics, Optics and Lasers in Engineering, 5, 1 (1984), p. 1-12.

15. Jones, J.D.C., Corke, M., Kersey, A.D., Jackson, D.A., Single-mode fiber-optic holography, J. Phys. E: Sci Instrum., 17 (1984), p. 271-273.

16. Dudderar, T.D., Gilbert, J.A., Franzel, R.A., Schamell, J.H., Remote vibration measurement by time averaged holographic interferometry, Proc. of the Fifth International Congress on Experimental Mechanics, Montreal, Quebec, Canada (1984), p. 362-366.

17. Hall, P. M., Dudderar, T. D., Argyle, J.F., Thermal deformations observed in leadless ceramic chip carriers surface mounted to printed wiring boards, IEEE Trans. Components, Hybrids and Manufacturing Technology, CHMT-6, 4 (1983), p. 544-552.

18. Dudderar, T.D., Hall, P.M., Gilbert, J.A., The effect of laminate asymmetry on the thermal deformation response to power dissipation in multilayer printed wiring boards, currently under review by Experimental Mechanics (1984).

19. Dudderar, T.D., Gilbert, J.A., Real-time holographic interferometry through fiber optics, currently under review by Applied Physics E : Scientific Instruments (1984).

20. Gilbert, J.A., Dudderar, T.D., Bennewitz, J.H., The application of fiber optics to remote speckle metrology using incoherent light, Optics and Lasers in Engineering, 3, 3 (1982), p. 183-195.

21. Dudderar, T.D., Gilbert, J.A., Fiber optic measurement of the deformation field on a remote surface using numerically processed white light speckle, Applied Optics, 21, 19 (1982), p. 3520-3527.

22. Dudderar, T.D., Gilbert, J.A., Boehnlein, A.J., Schultz, M.E., Application of fiber optics to speckle metrology - a feasibility study, Exp. Mech., 23, 3 (1983), p. 289-297.

23. Bennewitz, J.H., Dudderar, T.D., Gilbert, J.A., Objective speckle measurement, Proc. of the 1983 Spring Conf. on Exp. Mech., SESA, Cleveland, Ohio (1983), p. 113-118.

24. Dudderar, T.D., Gilbert, J.A., Bennewitz, J.H., Numerical correlation of remote objective speckle patterns for displacement measurement, Proc. of the Fifth International Congress on Exp. Mech., Montreal, Quebec,

Canada (1984). p. 281-286.

25. Dudderar, T.D., Gilbert, J.A., Bennewitz, J.H., Displacement sensitivity in remote objective speckle metrology, currently under review by Experimental Mechanics (1984).

26. Gilbert, J.A., Dudderar, T.D., Applications of fiber optics to coherent metrology for the study of material deformations and structural mechanics, to be presented at the Army Symposium on Solid Mechanics, Newport, Rhode Island, October 1-3, 1984.

SUMMARY OF THE MOST IMPORTANT RESULTS

In holographic applications fiber optic components may be used in three ways. Individual single mode fibers (SMFs) may be used to provide object beam illumination for the test subject and/or reference beam illumination for the hologram itself. In either case, flexible optical fibers provide convenience and simplicity. Moreover, SMFs are considerably more effective than multimode fiber optics because of their far lower spatial noise and greater stability. In addition to their advantages as convenient illuminators, fiber optic components may also be used to transmit the reflected wavefront back from the test object to the hologram. Adding this fiber optic link facilitates access to test surfaces that may otherwise be optically inaccessible or physically remote from the laser bench or test station where the hologram is recorded, and raises the prospects of designing a flexible holographic "probe". Such a sophisticated system would incorporate fiber optics for both illumination and return imaging, analogous to a medical endoscope but with holographic and even holographic interferometric capabilities of great potential value in experimental mechanics. Unfortunately, complete success is not yet here. The need to transmit an image requires that this third fiber optic link be a coherent fiber optic image bundle. Since all such bundles presently available are constructed from thousands of fine multimode optical fibers, they are significantly less stable (for holographic applications) than are the SMFs used for illumination. This means that, with any combined single and multimode fiber optic

holography system wherein the coherent multimode fiber bundle (MMB) must transmit both amplitude and phase information, considerable care must be taken to secure the full length of the MMB against the deleterious effects of mechanical movement or vibration. Otherwise, such motions produce changes in the MMBs modal propagation characteristics during recording which degrade or completely eliminate the hologram. Nevertheless, such systems have been operated successfully both to record remote holograms and to make remote interferometric measurements by the time-averaged, double exposure and real time holo-interferometric techniques. The use of short exposure durations, as with a pulsed laser, has been demonstrated as another means of overcoming stability problems in so far as recording remote holograms is concerned, but cannot be expected to provide much relief when doing interferometry for all except those events which occur on a time scale shorter than that of the offending MMB disturbances. On the other hand, mixed mode holographic systems which do not entail the transmission of phase information via the MMB, such as remotely generated holograms of ultra-low spatial frequency (ULF holograms), are quite stable and effective for both holography and holographic interferometry. However, a true ULF probe system would be geometrically challenging and require an MMB of both large cross-section and the best possible resolution to provide both an acceptable signal-to-noise ratio and bandwidth needed for reconstructing complex wavefronts and/or interference patterns. Of course, the equivalent of a single mode flexible imaging bundle might be the best solution, but so far no one has demonstrated the ingenuity to produce one.

Speckle correlation techniques, like holographic interferometry, can also benefit from the use of SMF illuminators, although in this case only one such fiber optic link is required (there being no reference beam in speckle metrology). Indeed, many of the same things may be said about single versus multimode optical fibers for speckle applications that were said for holographic applications. However, speckle images may best be treated simply as intensity distributions which move with the test subject and nothing more. In this case the returning image stability requirements are greatly reduced and the MMB resolution becomes most important (as for the remote ULF holography). This is so because the resolution limit establishes the minimum useable characteristic speckle size of any remote speckle field to be transmitted via the MMB. Current experience with commercially available MMBs of intermediate cost and resolution require speckle patterns of relatively large characteristic size (at least 50μ) which can readily be generated using unimaged objective laser speckle at the input end and, on the output end, imaging into a vidicon camera/digitizer system for recording and numerical correlation. For a given objective speckle size, such a numerical correlation system can readily measure inplane displacements over a much wider range than can be achieved by optical correlation methods, but is limited to point-by-point studies (unless developed from arrays of illuminating SMFs or some sort of scanning illumination system). On the other hand, remote full field measurements can be made using coarse "white light" or artifically painted speckle fields. These can

be imaged into an MMB and fed into the vidicon/camera digitizer for subsequent numerical analysis of displacements over a field of view. Both of these approaches permit making comparisons between a succession of states or surface positions so that time histories can be obtained. Furthermore, the use of higher resolution MMBs and more (light) sensitive vidicon camera systems should facilitate the application of fiber optics to <u>subjective</u> laser speckle metrology which would provide the advantages of both coherent light speckle and full field displacement measurement via a flexible probe system.

PUBLICATIONS

1. Gilbert, J.A., Herrick, J.W., Holographic displacement analysis with multimode fiber optics, Experimental Mechanics, 21, 8 (1981), p. 315-320.

2. Gilbert, J.A., Schultz, M.E., Boehnlein, A.J., Remote displacement analysis using multimode fiber optic bundles, Experimental Mechanics, 22, 10 (1982), p. 398-400.

3. Dudderar, T.D., Gilbert, J.A., Fiber optic measurement of the deformation field on a remote surface using numerically processed white light speckle, Applied Optics, 21, 19 (1982), p. 3520-3527.

4. Gilbert, J.A., Dudderar, T.D., Bennewitz, J.H., The application of fiber optics to remote speckle metrology using incoherent light, Optics and Lasers in Engineering, 3, 3 (1982), p. 183-195.

5. Gilbert, J.A., Dudderar, T.D., Schultz, M.E., Boehnlein, A.J., The monomode fiber - a new tool for holographic interferometry, Experimental Mechanics, 23, 2 (1983), p. 190-195.

6. Dudderar, T.D., Gilbert, J.A., Boehnlein, A.J., Schultz, M.E., The application of fiber optics to speckle metrology, Experimental Mechanics, 23,3 (1983), p. 289-297.

7. Dudderar, T.D., Gilbert, J.A., Boehnlein, A.J, Achieving stability in remote holography using flexible multimode image bundles, Applied Optics, 22, 7 (1983), p. 1000-1005.

8. Dudderar, T.D., Gilbert, J.A., Fiber optic pulsed laser holography, Applied Physics Letters, 43, 8 (1983), p. 730-732.

9. Gilbert, J.A., Dudderar, T.D., Boehnlein, A.J., Ultra low frequency holographic interferometry using fiber optics, Optics and Lasers in Engineering, 5, 1 (1984), p. 1-12.

10. Gilbert, J.A., Dudderar, T.D., Nose, A., Remote deformaion field measurement through different media using fiber optics, currently under review by Optical Engineering (1984).

11. Dudderar, T.D., Gilbert, J.A., Bennewitz, J.H., Displacement sensitivity in remote objective speckle metrology, currently under review by Experimental Mechanics (1984).

12. Dudderar, T.D., Gilbert, J.A., Real-time holographic

interferometry through fiber optics, currently under review by Applied Physics E : Scientific Instruments (1984).

13. Dudderar, T.D., Hall, P.M., Gilbert, J.A., The effect of laminate asymmetry on the thermal deformation response to power dissipation in multilayer printed wiring boards, currently under review by Experimental Mechanics (1984).

14. Dudderar, T.D., Gilbert, J.A., Franzel, R.A., Schamell, J.H., Remote vibration measurement by time averaged holographic interferometry, to be submitted for publication in Experimental Techniques (1984).

PRESENTATIONS

1. Gilbert, J.A., Herrick, J.W., Holographic displacement analysis with fiber optics, Proceedings of the 1980 Fourth SESA International Congress on Experimental Mechanics, Boston Massachusetts, May 25-30, 1980, p. 116.

2. Gilbert, J.A., Schultz, M.E., Boehnlein, A.J., Remote displacement analysis using multimode fiber optic bundles, Proceedings of the 1981 Spring Meeting of the Society for Experimental Stress Analysis, Dearborn, Michigan, May 31-June 4, 1981, p. 41-45.

3. Gilbert, J.A., Schultz, M.E., Stress analysis using fiber optics, Proceedings of the Eighth Canadian Congress of Applied Mechanics, Moncton, N.B., Canada, June 7-12, 1981, p. 533-534.

4. Dudderar, T.D., Gilbert, J.A., Schultz, M.E., Boehnlein, A.J., The application of fiber optics to speckle metrology, Proceedings of the 1982 Joint Conference on Experimental Mechanics, SESA/JSME, Oahu-Maui, Hawaii, May 23-28, 1982, p. 594-598.

5. Gilbert, J.A., Dudderar, T.D., Schultz, M.E., Boehnlein, A.J., The monomode fiber - a new tool for holographic interferometry, Proceedings of the 1982 Joint Conference on Experimental Mechanics, SESA/JSME, Oahu-Maui, Hawaii, May 23-28, 1982, p. 920-922.

6. Bennewitz, J.H., Dudderar, T.D., Gilbert, J.A., Objective speckle measurement, Proceedings of the 1983 Spring Meeting of the Society for Experimental Stress Analysis, Cleveland, Ohio, May 15-19, 1983, p. 113-118.

7. Gilbert, J.A., Dudderar, T.D., Nose, A., Remote displacement analysis through different media using fiber optics, Proceedings of the 1983 Meeting of the Society for Experimental Stress Analysis, Cleveland, Ohio, May 15-19, 1983, p. 424-430.

8. Dudderar, T.D., Gilbert, J.A., Bennewitz, J.H., Numerical correlation of remote objective speckle patterns for displacement measurement, Proceedings of the Fifth International Congress on Experimental Mechanics, Montreal, Quebec, Canada, June 10-15, 1984, p. 281-286.

9. Dudderar, T.D., Gilbert, J.A., Franzel, R.A., Schamell, J.H., Remote vibration measurement by time averaged holographic interferometry, Proceedings of the Fifth International Congress on Experimental Mechanics, Montreal, Quebec, Canada, June 10-15, 1984, p. 362-366.

10. Gilbert, J.A., Dudderar, T.D., Applications of fiber

optics to coherent metrology for the study of material deformations and structural mechanics, to be presented at the Army Symposium on Solid Mechanics, Newport, Rhode Island, October 1-3, 1984.

11. Gilbert, J.A., Dudderar, T.D., Van Rossum, E.J., Hsu, M.J., Bennewitz, J.H., Remote objective speckle displacement sensitivity, to be presented at the 1984 Fall Meeting of the Society for Experimental Stress Analysis, Milwaukee, Wisconsin, November 4-7, 1984.

12. Gilbert, J.A., Dudderar, T.D., Applications of fiber optics to coherent metrology, currently under consideration for presentation at the 1985 SESA Spring Conference on Experimental Mechanics, Las Vegas, Nevada, June 9-13, 1985.

PARTICIPATING SCIENTIFIC PERSONNEL

The graduate students listed below were partially or fully funded under Contract No. DAAG 29-80-K-0028. All research was conducted under the direct supervision of the principal investigator.

1. Herrick, J.W.
   Employer: General Electric Medical Systems Division
   Degree: M.S. awarded in 1980
   Thesis: Holographic displacement analysis using fiber optics and wave front modulation
   Publications: see #1 on page 15
   Presentations: see #1 on page 17

2. Schultz, M.E.
   Employer: General Dynamics
   Degree: M.S. awarded in 1982
   Thesis: The application of fiber optics to holography
   Publications: see #2, #5 and #6 on page 15
   Presentations: see #2, #3, #4 and #5 on page 17

3. Nose, A.
   Employer: Yamaha
   Degree: M.S. awarded in 1982
   Thesis: Remote displacement analysis using fiber optics through different media
   Publications: see #10 on page 15
   Presentations: see #7 on page 17

4. Boehnlein, A.J.
   Employer: Biotronics, Inc.
   Degree: M.S. awarded in 1982
   Thesis: The application of fiber optics to ultra low frequency holography
   Publications: see #2, #5, #6, #7 and #9 on page 15
   Presentations: see #2, #4 and #5 on page 17

5. Schamell, J.H.
   Employer: Beloit Corporation
   Degree: M.S. awarded in 1983
   Thesis: The development of a hybrid method for stress analysis
   Publications: see #14 on page 16
   Presentations: see #9 on page 17

6. Bennewitz, J.H.
   Employer: Bell Laboratories
   Degree: M.S. awarded in 1983
   Thesis: The development of an objective speckle measurement system utilizing fiber optics and photoelectronic-numerical processing
   Publications: see #4 and #11 on page 15
   Presentations: see #6 and #8 on page 17

7. Van Rossum, E.J.
   Employer: Grumman Aerospace
   Degree: M.S. awarded in 1984
   Thesis: Photo-numeric measurement of two-dimensional displacements using artificial and laser speckle
   Presentations: see #11 on page 18

8. Franzel, R.
   Employer: General Electric Medical Systems Division
   Degree: M.S. expected in 1984
   Thesis: A high sensitivity moire approach to hybrid analysis
   Publications: see #14 on page 16
   Presentations: see #9 on page 17

9. Hsu, M.J.
   Employer: University of Wisconsin-Milwaukee
   Degree: M.S. in progress
   Thesis: Displacement sensitivity for objective speckle measurement
   Presentations: see #11 on page 18

10. Chern, J.
   Employer: University of Wisconsin-Milwaukee
   Degree: M.S. in progress
   Thesis: Photoelectronic/numerical processing of holographic interferometric fringe data

Note: T.D. Dudderar and P.M. Hall are research scientists at Bell Laboratories located in Murray Hill, New Jersey.

7

END

FILMED

10-84

DTIC